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DEVELOPMENT OF S-BAND LOW-NOISE PERIODIC PERMANENT MAGNET TRAVELING-WAVE TUBE

B. P. Israelsen

Watkins-Johnson Company
3333 Hillview Avenue
Palo Alto, California

W-J 62-604R3

20 December 1962

Contract No. AF 30(602)-2694

Prepared
for
Rome Air Development Center
Air Force Systems Command
United States Air Force

Griffiss Air Force Base
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ABSTRACT

An additional focusing test using two ferrite stacks opposed so as to yield a reversed-field was made. Performance was only moderate, with 75 percent beam transmission being obtained at rated helix voltage. A very promising magnetic circuit configuration using a straight-field Alnico 5 magnet has been devised. The external fringing field is effectively shielded and the cathode field is peaked to about 750 gauss. Two tubes have been built with stepped-diameter gun bulbs, permitting the use of a gun stack with less than 1/2-inch diameter. One of these operated with a best noise figure of 3.1 db. A half-inch pin base has been developed, in addition to a coupler with 3/4-inch diameter. These size reductions permit the use of a small, light-weight magnet.

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INTRODUCTION

This development program is concerned with the achievement of low-noise amplification in a focusing structure using periodic permanent-magnet focusing. The objective is to realize a noise figure of 3 db in such a device, with small-signal gain of 25 db, these performance figures to be realized over the frequency band 2.7-3.3 Gc. In addition, the phase stability of the tube should be ± 5 degrees.

The achievement of these goals entails two principal problems; first, the development of a focusing structure capable of yielding nearly perfect beam transmission, and secondly, modification of the tube design so as to yield substantially the noise properties in the permanent magnet system as in a solenoid. This report describes work done in both reversed-field and straight-field focusing. A significant advance in the mechanical design of the tube is described. It permits a substantial reduction in the diameter of the tube capsule, thus easing some of the size restrictions on the magnet. Finally, certain characteristics of the tube with regard to phase shift of the rf signal are described.

DISCUSSION

A. Status of Permanent-Magnet Focusing Methods

Reversed-Field

Work using opposed Alnico 5 magnets in a reversed-field configuration was described in the last Quarterly Report. Additional work was performed this quarter using a stack of ceramic magnets with polarity reversal at the middle. A cross-sectional sketch of this stack is shown in the Fig. 1. The individual magnets are ferrite discs 1.4 inches in diameter with a center hole 0.75 inches in diameter, and 1/2 inch thick. They are separated by Hipernik discs 0.014 inch thick, with a 0.25-inch center hole. The field developed by this stack reaches a maximum of 900 gauss near the ends, falling to 750 gauss in the middle of the straight-field sections. Focusing performance was only fair, beam transmission being 75 percent with the helix at 180 volts.

Tests to date seem to indicate that the adjustments are somewhat critical to achieve proper reversed-field focusing. The advantages of small size and light weight might be offset by this critical nature.

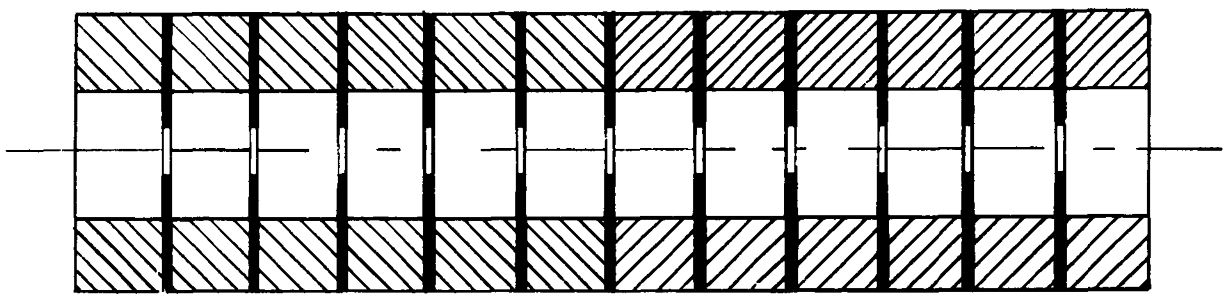

Fig. 1 - Cross sectional sketch of reversed-field ferrite magnet assembly. The field strength varies between about 900 gauss near the ends to 750 gauss near the center of the uniform-field sections.

The problem is more pronounced, of course, the lower the beam voltage. With the present helix voltage of 180 volts, it is questionable whether reversed-field focusing is the optimum solution for best repeatable low-noise performance.

PM-PPM Focusing

No additional work has been done this quarter on focusing in a combined straight and periodic field.

Straight-Field Focusing

Recent developments lead to renewed consideration of the advantages of straight-field focusing. One of these is the ability to shield the fringing field of the magnet sufficiently to eliminate defocusing effects caused by other magnets or iron objects, and the other is the development of a tube and coupler with considerably reduced diameter.

The solid curve of Fig. 2 is a plot of axial field of a seven-inch long Alnico 5 permanent magnet held within a double-walled steel shield. The dashed curve shows longitudinal field measured on the outside wall of the 4.5-inch diameter outer shield. The dotted curve shows longitudinal field at the same diameter in the absence of shielding. Two features are significant. First, the residual external field is sufficently low that multiple units of the same type can be operated in close proximity without interference. Secondly, the field on the axis is reduced by this shielding by approximately 150 gauss. For best noise performance it is necessary to have a field of about 750 to 800 gauss at the cathode of the tube. Field peaking to this value can be realized by the assembly shown in the photograph of Fig. 3, along with the magnet and inner shield can. In the foreground is a stainless steel tube on which is wound an iron wire field straightener for shunting transverse field components. At the right end is a pole piece and field peaker. These two elements form a reentrant structure which boosts the field in the region of the cathode to greater than 750 gauss. The center tubing has 3/4-inch O. D. In the following section is described a coupler designed to fit into this tubing. This geometry is expected to provide a field of sufficient strength to make low-noise operation entirely feasible.

B. Reduction of Tube Capsule Diameter

In any of the three PM focusing techniques, outside diameter of the tube capsule is an important parameter.

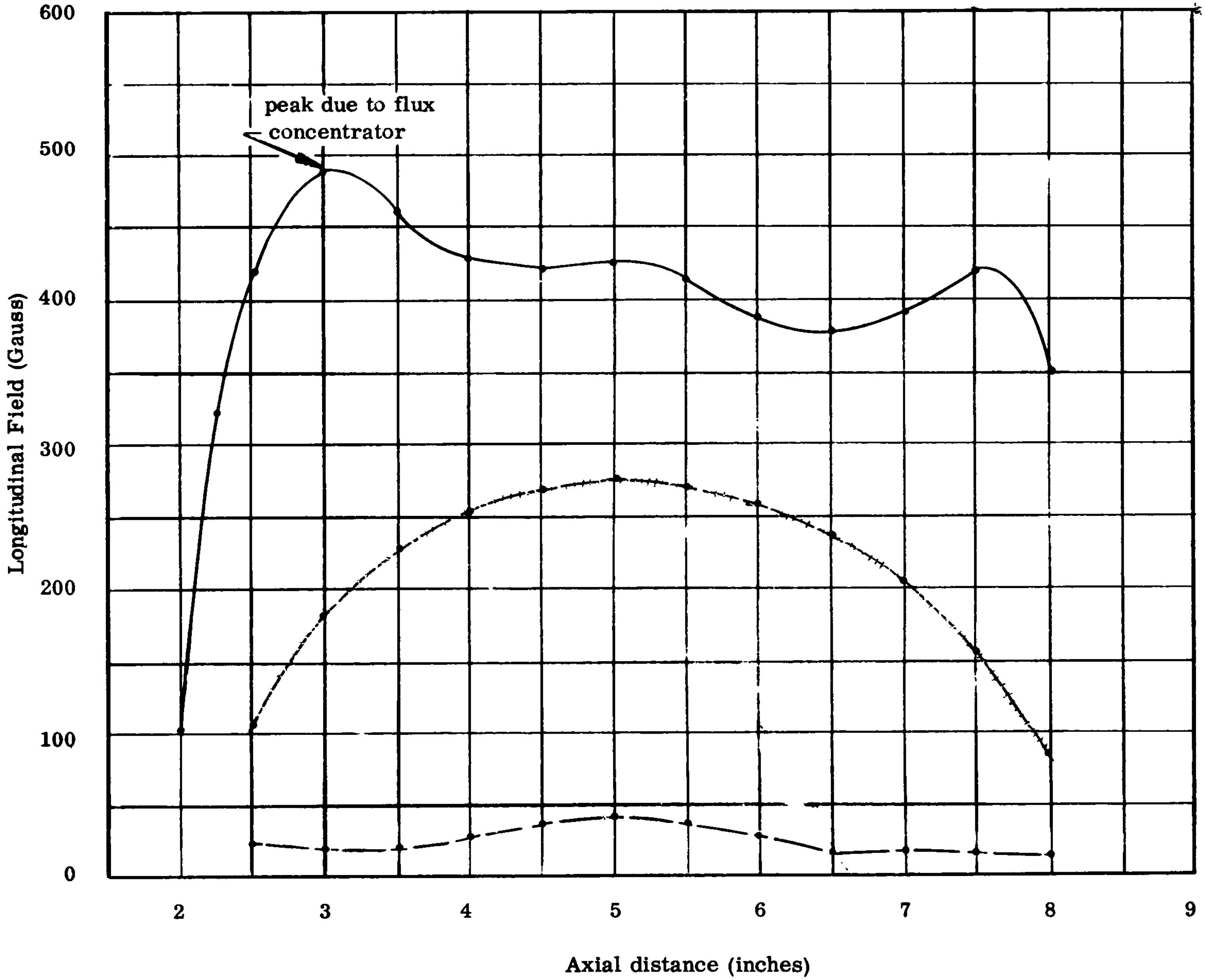

Fig. 2 - Field plots for a seven-inch Alnico 5 magnet within a double-walled steel shield 4.5 inches in diameter. The solid curve is field along the axis of the magnet. The dashed curve shows the axial component of external fringing field along the exterior of the shield, and the dotted curve indicates the same field in the absence of the shield.

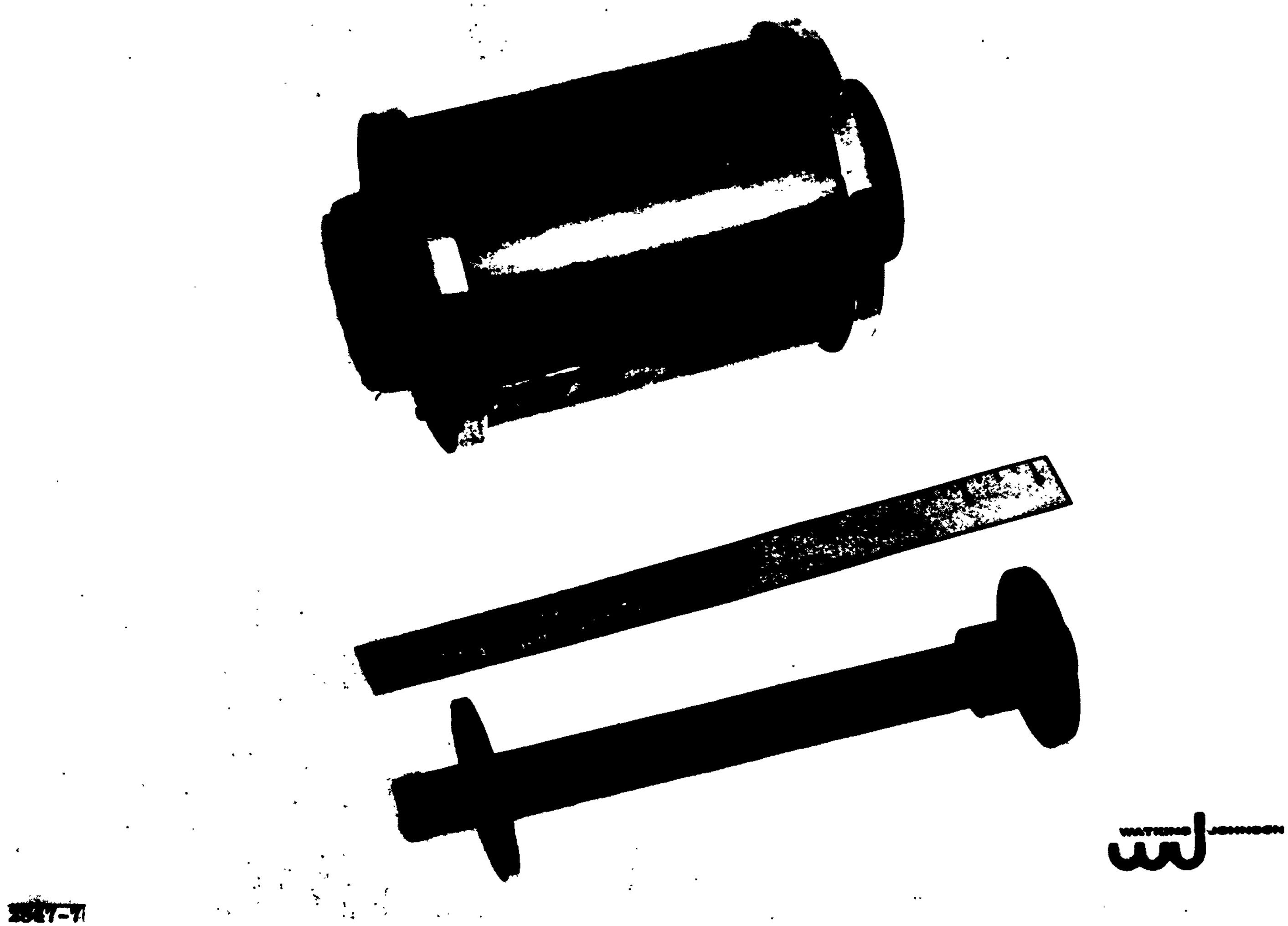

Fig. 3 - Photograph of magnet with inner shield can, and field peaker and straightener assembly. The pole piece and flux concentrator at the right end raises the field at the cathode to approximately 750 gauss.

It determines the minimum inside diameter of the focusing magnets. It is desirable to have this diameter as small as possible. In straight-field or reversed-field focusing, the length and weight of the magnet are highly dependent on the I. D. This is illustrated in the sketch of Fig. 4, which is a plot of weight of a straight-field magnet suitable for focusing a beam 5 inches long. These curves are based on the assumption that the magnet length should be equal to the beam length plus twice the inside diameter, which tends to be slightly pessimistic.

The advantage of reducing magnet length is even more striking when the effects of shielding the external field are examined. The leakage flux around a straight-field magnet increases very rapidly with magnet length, as described by Glass[1]. Accordingly, the difficulty of shielding increases rapidly with increasing length. For example, increasing the magnet length from 7 to 7.5 inches approximately doubles the external field at the surface of the shield.

The gun bulb is generally the principal element in determining capsule diameter. To effect a substantial reduction in bulb diameter, it is necessary to reduce the diameter of the gun anodes and of the pin base. Reduction of the anode size has been accomplished successfully as shown in the photograph of Fig. 5. This shows a tube with a stepped-diameter bulb. While the pin base is unchanged, the gun proper has been reduced sufficiently to be used in a bulb with .55 inch O. D. An additional modification is that the input rf pin is brought through the glass radially rather than axially. This renders the input match less sensitive to stray coupling effects, such as to the anodes.

Two tubes of this type have been built. One failed to operate properly because of a faulty helix. The other yielded a noise figure less than 5 db over the full 2 to 4 Gc octave, reaching 3.1 db at 2.6 Gc. Gain was approximately 23 db.

The next step is to build a tube with a uniform gun bulb diameter of .55 inch. The required pin base, having a diameter of .53 inch, has been developed. A coupler has also been built, with appropriate size reductions. This coupler is shown in the photograph of Fig. 6. The basic structural element is a brass tube with certain axial sections milled away to form a half-shell. Input, mid-section, output and collector blocks are located at the full-round sections. This coupler is adapted to match the radial input pin. It includes a quarter-wave stub at the input for maintaining the helix at system ground. In addition, this stub provides an extra degree of freedom in matching the input, making possible an excellent broadband VSWR.

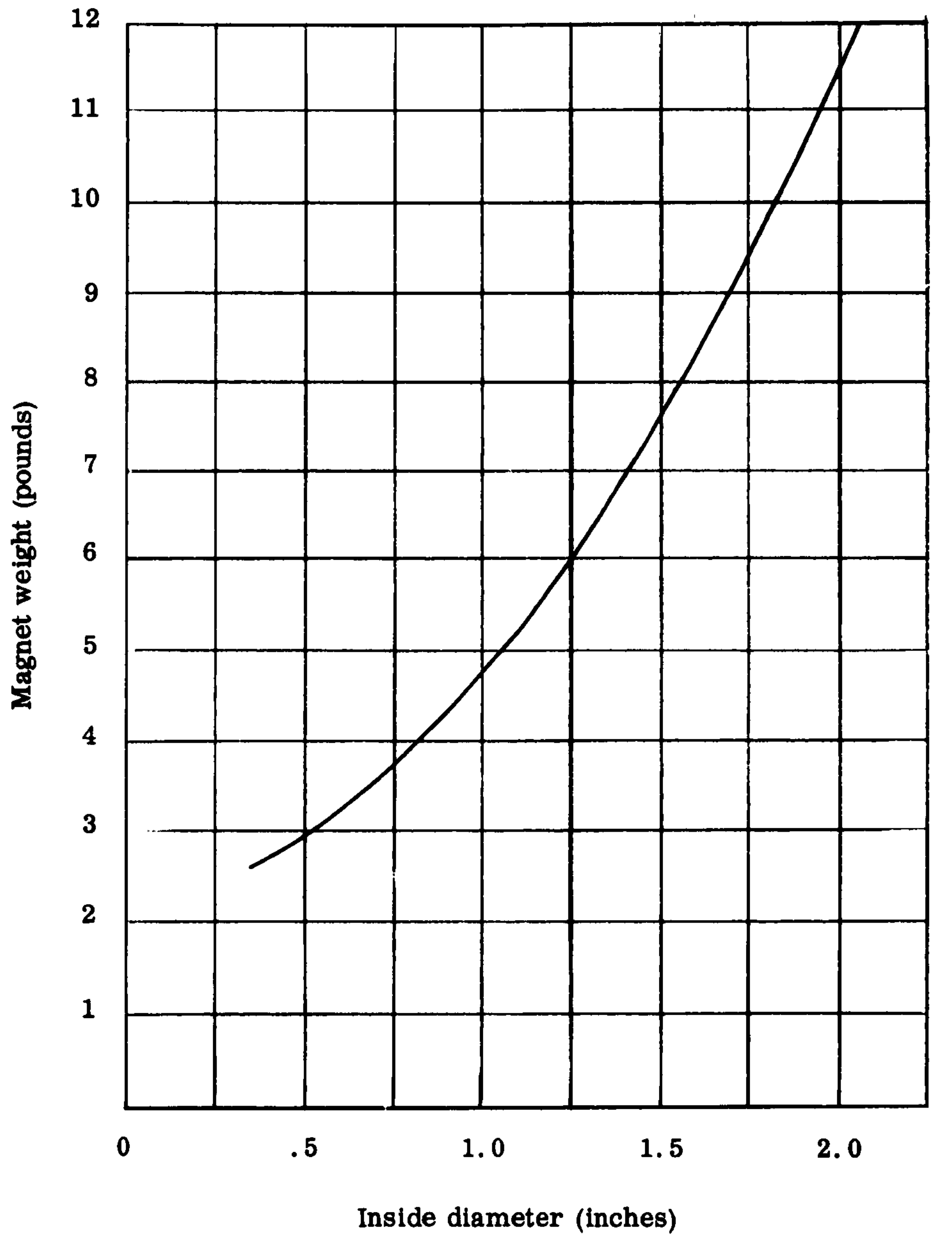

Fig. 4 - Magnet weight vs inside diameter, for focusing a five inch long beam.

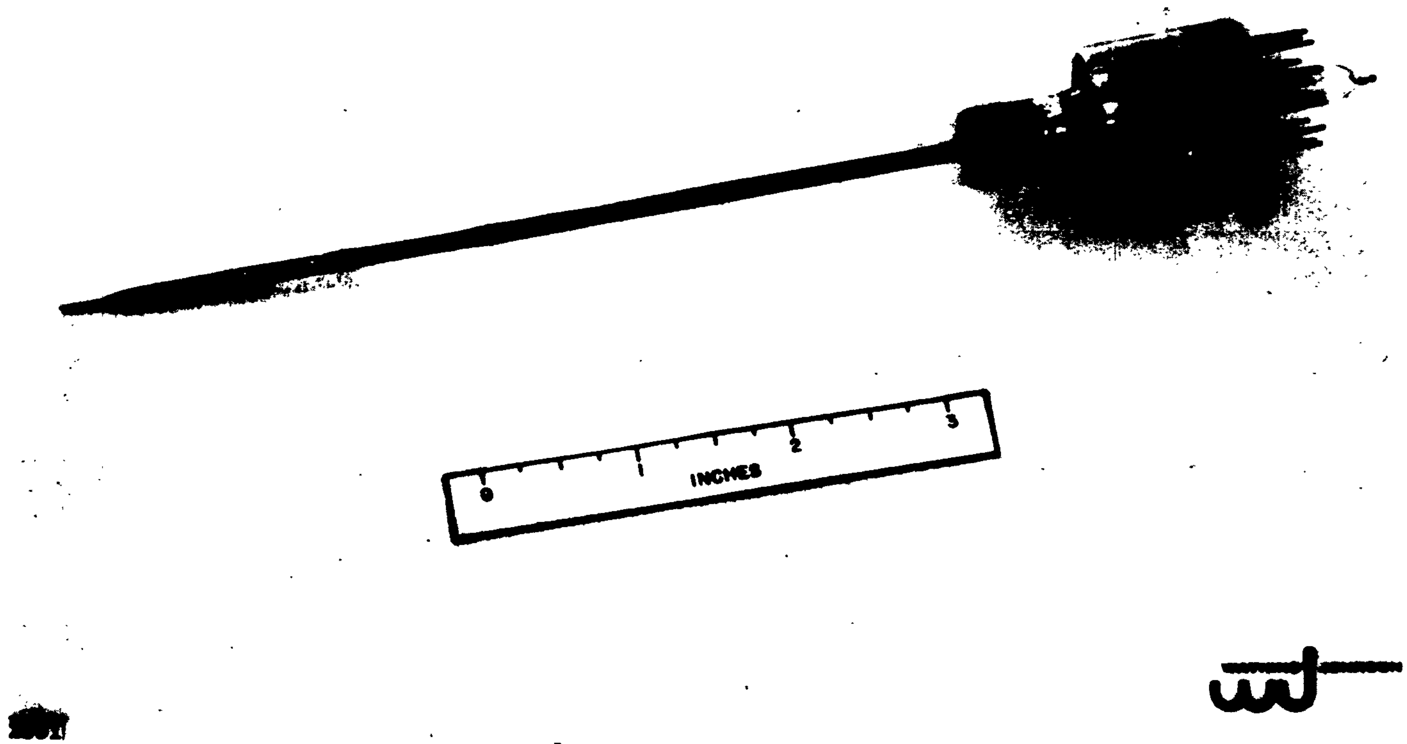

Fig. 5 - This photograph shows the stepped-diameter bulb built to test the feasibility of reducing the electron gun diameter. A miniature pin base has been developed which will permit the entire bulb to be reduced to 0.55 inch diameter.

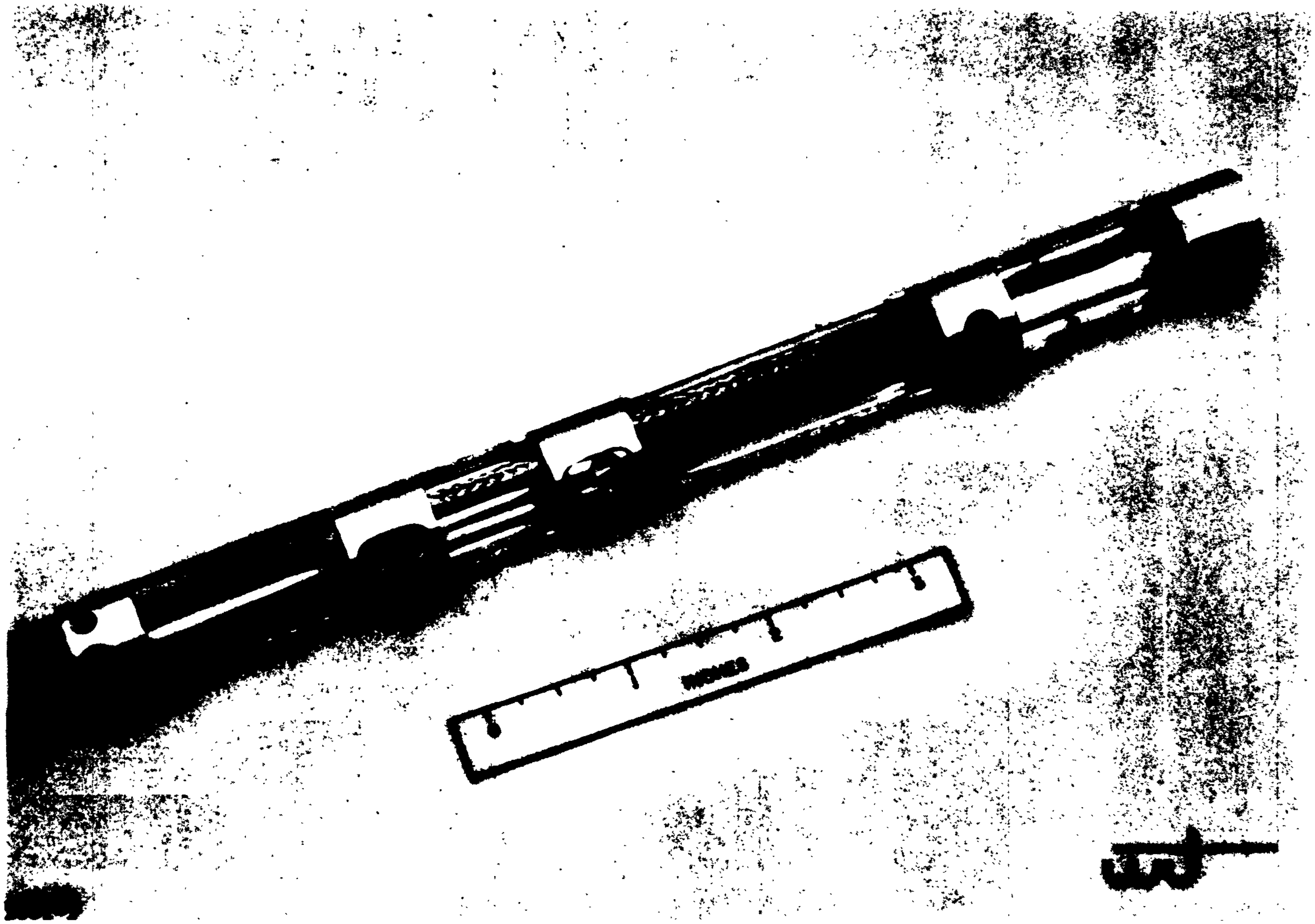

Fig. 6 - Photograph of coupler designed to fit 3/4-inch capsule. The gun bulb,which has an O. D. of 0.55 inch, is held at the right end.

The alternative, a dc block in the rf input line, is much less desirable since it adds additional input loss which degrades noise figure. The coupler fits in a stainless steel capsule with 3/4-inch O. D. The resulting advantage in terms of magnet design is obvious. This size reduction is believed to represent a very definite advance because of the simplification in magnet requirements. Minimum length and diameter are both sought in the magnet, to render shielding easier and to reduce bulk.

C. Phase Shift

Total phase shift through a traveling-wave tube is given by the expression of Eqn (1)

$$\phi = 15,400 \frac{Lf}{\sqrt{V}} \quad \text{degrees} \tag{1}$$

where L is total signal path length along the helix in inches

f is signal frequency in Gc

V is helix voltage in volts

Two operating parameters with respect to phase shift are important in a traveling-wave tube. The first is phase stability with respect to voltage changes in the power supply. The other is variation of phase shift with frequency. Ideally, TWT phase shift increases linearly with frequency. The principal deterrent to a linear phase characteristic is reflections along the signal path. Multiple reflections cause standing waves which yield periodic variations of phase shift vs frequency.

Measurements of phase sensitivity of the WJ-253 with respect to helix voltage yield a value very close to 25 degrees/volt. Generally the helix is the most sensitive element with respect to phase shift. From the above figure, it is evident that a change in helix voltage of 0.2 volt would cause a change in over-all tube phase shift of 5°. Based on a helix voltage of 180 volts, this represents 0.11 percent variation. To eliminate power supply changes from consideration in their effect on phase shift, a ripple and regulation specification of 0.05 percent should be adequate. The fact that anode voltage variations partially cancel the effect of helix voltage changes is also helpful in this regard.

CONCLUSIONS

Moderate success has been attained with reversed-field focusing. With certain mechanical modifications it appears that full beam transmission can be achieved, but at the cost of being quite critical in adjustment.

Straight-field focusing appears quite promising, based on the ability to shield an Alnico magnet satisfactorily. The use of a straight-field magnet is aided by reducing the capsule diameter to a minimum.

A tube capsule has been built which will accomodate a gun bulb of 0.55 inch diameter. The diameter of this capsule is 0.75 inch. Reduction of the gun stack diameter has been proven feasible. Also, a pin base just over 1/2 inch in diameter has been built, which will allow construction of a tube to match the coupler described above.

RECOMMENDATIONS

Tubes having half-inch gun bulbs should be built and tested. Additional couplers and magnet assemblies using straight-field Alnico 5 magnets should be built. A complete package design should be worked out. Three units should be assembled for delivery.

REFERENCES

1. M. S. Glass, "Distribution of leakage flux around a TWT-focusing magnet-a graphic analysis", Proc. IRE, vol. 46, p. 1751 ff, October, 1958.

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December 1962, 12 pg. incl. illus.
(Proj. 4506; Task 450602)

Unclassified report

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